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A near field method for calibrating l.f./m.f. field strength measuring receivers

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Summary

The method involves setting up a short vertical monopole on the ground in an open space. There is an accurate solution for the electromagnetic field at any point, transmitted from the monopole. It is possible to calibrate both electric and magnetic field detectors, and to calibrate an antenna mounted on a vehicle. The practical aspects are covered in some detail.

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A NEAR FIELD METHOD FOR CALIBRATING L.F./M.F. FIELD STRENGTH MEASURING RECEIVERS

A.P. Robinson B.Sc., A.R.C.S.

List of Symbols

E	electric field
H	magnetic field
η_o	E/H ratio in free space (or characteristic impedance of free space) = 120π ohm
ω	angular frequency
β	propagation constant or wave-number (2π/wavelength)
(ρ,ϕ,z)	position in cylindrical polar co-ordinates
E_z	vertical electric field component (i.e. in z-direction)
H_ϕ	tangential magnetic field component (i.e. in ϕ-direction)
h	height of top of monopole above ground
a	radius of rod or tube which comprises monopole
Z'_o	semi-empirical characteristic impedance of monopole
I_m	current at maximum of sinusoidal current distribution, of which the distribution on the monopole is assumed to be a part (loop current)
I_B	current at base of monopole
V_B	potential w.r.t. earth at base of monopole
j	$\sqrt{-1}$

1. Introduction

Conventional field strength meters usually detect the magnetic field component. Interest has recently arisen however in the direct measurement of the strength of the electric field associated with a broadcast signal at l.f. and m.f. This is because a significant number of receivers (car radios in particular) use whip antennas which detect the electric field, and because it is now appreciated that the ratio between the electric and magnetic fields can vary substantially from the free space value.

Although the majority of field strength measuring receivers for l.f. and m.f. have loop antennas and respond to the magnetic field, the measurements are usually expressed in volts per metre, as if an electric field is being measured, whose strength is related by the free space ratio to the magnetic field strength. A calibration system has existed at BBC Research Department for some years. The system suits measuring receivers having loop antennas of about 0.15 m radius. It is similar to a method used by the United States National Bureau of Standards[1] and involves a transmitting loop which sets up a known magnetic field.

In order to measure both the electric and magnetic field strengths at l.f. and m.f., the BBC RC1M/21 receiver[2] has been developed. A new calibration method was required, which would provide a known electric field strength, so that the whip antenna of this receiver could be calibrated.

We now consider the requirements which the calibration method should satisfy. The RC1M/21 is normally installed in a vehicle, and the antenna which is in use is mounted on a roof rack. The vehicle body forms part of the counterpoise for the whip antenna so it is desirable to calibrate this antenna while it is in position on the vehicle.

Thus the field we set up should be reasonably uniform over the volume occupied by the vehicle and antenna. We can achieve this if the vehicle is more than about 5 to 10 m away from the transmitting antenna. The electrostatic, inductive and radiation contributions to the resultant field may all need to be taken into account at distances over 10 m, thus an arrangement is required for which a complete solution for the electromagnetic field is available and which can be realised in practice. It would be an advantage if a known magnetic field is obtained at the same time, especially if the *E* to *H* ratio can be estimated at least as accurately as either *E* or *H* individually. Then the loops can also be calibrated and the receiver used for accurate measurements of the *E* to *H* ratio.

2. Theory

Difficulties often arise when working in the near field of a transmitting antenna because full expressions for the fields have only been found in a few special cases. The method chosen affords an accurate solution and meets the criteria mentioned above. The method is to erect a vertical monopole with its base close to the ground, as shown in Fig.1. Fig.1 also indicates the definitions of a number of quantities. From the figure,

$$r_0 = \sqrt{\rho^2 + z^2}$$

$$r_1 = \sqrt{\rho^2 + (h-z)^2}$$

$$r_2 = \sqrt{\rho^2 + (h+z)^2}$$

Then, in the usual complex notation, the required field components at a point P are given by:[3]

$$E_z = -\frac{j\eta_o I_m}{4\pi}\left(\frac{e^{-j\beta r_1}}{r_1} + \frac{e^{-j\beta r_2}}{r_2} - \frac{2e^{-j\beta r_0}\cos\beta h}{r_0}\right) \qquad \ldots\ldots\ldots\ldots (1)$$

$$H_\phi = \frac{jI_m}{4\pi\rho}\left(e^{-j\beta r_1} + e^{-j\beta r_2} - 2e^{-j\beta r_0}\cos\beta h\right) \qquad \ldots\ldots\ldots\ldots (2)$$

(Note that numbers containing hidden dimensions have been eliminated from eqs. (1) and (2).) We shall discard the phase information and take the r.m.s. values of alternating quantities.

Two assumptions are made in obtaining these results. First, that the ground is flat and highly conducting so that a perfect ground reflection is obtained. Over the distances we are considering here, provided the ground is level, it can be taken as flat. By consulting standard propagation curves we see that ground of moderate conductivity only begins to attenuate the field strength significantly at distances over 1 km from the transmitter. Thus the first assumption is easy to satisfy. The second assumption is that the current distribution along the monopole is sinusoidal; this is a good approximation provided that the monopole is a cylinder (not tapering), thin compared with its length, and short compared with a wavelength. Programs have been written to calculate the *E* and *H* fields, both in FORTRAN and for a programmable calculator.*

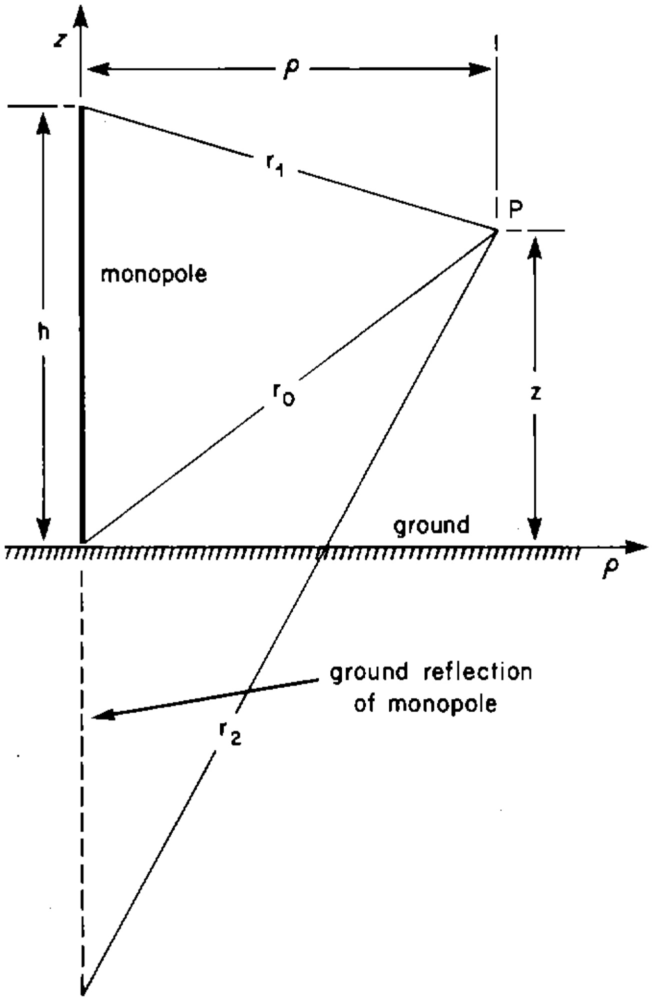

Fig. 1 - Geometry of calibration method

Regarding the variables in eqs. (1) and (2), the distances can be obtained from measurements of h, ρ and z. β can be found from the frequency

$$\beta = \frac{\omega}{c}$$

*** It should be noted that the answers come from small differences between large numbers, especially as ρ increases. Thus additional significant figures are required in the intermediate results.**

where c is the velocity of propagation ($\approx 3 \times 10^8$ m/s). The loop current I_m can be calculated from the base current I_B, again assuming a sinusoidal current distribution:

$$I_m = \frac{I_B}{\sin\beta h}$$

The current supplied at the foot of the monopole may be measured with a thermocouple ammeter, but this will include the current flowing into the capacitance of the base insulator. We can separate the two parts of the current by measuring the capacitance of the base and the impedance of the monopole. In order to place the monopole in position we must mount it on the base insulator; thus we have to measure the combined admittance of the monopole and its base, and then subtract the admittance of the base. A short monopole is almost purely capacitive; its reactance is given by[3]

$$X = Z'_0 \cot \beta h \qquad (3)$$

where Z'_0, the characteristic impedance, is given by the semi-empirical expression[3,4]

$$Z'_0 = 60[\ln(h/a) - 1] \text{ ohm} \qquad (4)$$

provided $a \ll h$. The measurements can be compared with the values obtained from these expressions.

It seems more convenient to measure the base voltage than the current supplied. In this case, having found the impedance of the monopole, we can immediately obtain I_B.

3. Practical implementation

We begin by fixing the dimensions of the monopole. It needs to be reasonably easy to set up, so its height is limited to about 10 m. For a given base voltage and mast height, the field strength only varies slowly with the radius of the monopole. Taking a representative radius, a few calculations suffice to show that a base voltage of about 300 V is required with a 10 m monopole to give useful field strengths in the l.f. band. In the m.f. band, $V_B \approx 200$ V and $h \approx 5$ m are sufficient, and these values will be used since the radiated power must be kept to a minimum. To avoid errors, it is essential to keep clear of the mast when it is energised.

Fig. 2 shows the mast which was constructed. A stayed mast was chosen so that it would be light, for ease of erection. Though light, the mast must be sufficiently rigid to resist flexing in the wind. To meet these requirements, aluminium scaffold pole of nominal diameter 25.4 mm was chosen. The mast is stayed at the top and halfway up so that half of it can be used when calibrating at m.f. Four stays are used because it is much easier to adjust opposite pairs of stays to make the mast vertical, than to adjust three stays at once. To facilitate transport, the mast is divided into four sections which are joined by clamps. The mast shown has a length of 10.29 m, or 5.15 m when only half is in use.

Two sheets of 25 mm mesh, each 2.4 m by 1.2 m, were placed on the ground as an earth mat. This is an adequate earth because the impedance between the mat and the earth is much smaller than the impedance of the monopole.

Fig. 3 shows the mast being pulled into position. The clamp at the foot of the mast pivots about a horizontal axis and accommodates two poles at right angles. The mast is raised with the aid of a derrick, which the operator is holding. It is a steel pole with a hook about 2.2 m from the pivot. The procedure for setting up the mast is as follows. The mast is mounted in the base and assembled on the ground along a line to a stay anchorage point. The three stays which will reach from each level are attached to their anchorage points. The derrick is mounted vertically in the base and the remaining stays attached to the hook. These stays are tensioned and the derrick is pulled through an arc down to the ground, thereby raising the mast. The stays are then extended and attached to their anchorages, and the derrick is removed.

The generation and accurate measurement of the voltages required to drive the mast is not entirely straightforward. A block schematic of the transmitter is shown in Fig. 4. No attempt was made to match to the mast because of its low radiation resistance. Most of the power delivered by the r.f. amplifier is dissipated in the transformer. The transformer secondary is tuned by the combination of the mast and the variable capacitor. Care was needed over the voltage and current ratings of the tuned circuit components. For the values chosen, the circulating current is about 0.5 A at the low frequency end of each band. The transformer for l.f. was wound on a ferrite core with several wires in parallel. It has one turn on the primary and 30 on the secondary. The transformer for m.f. is air-cored and wound with heavy gauge wire, having 7 primary turns and 50 secondary turns.

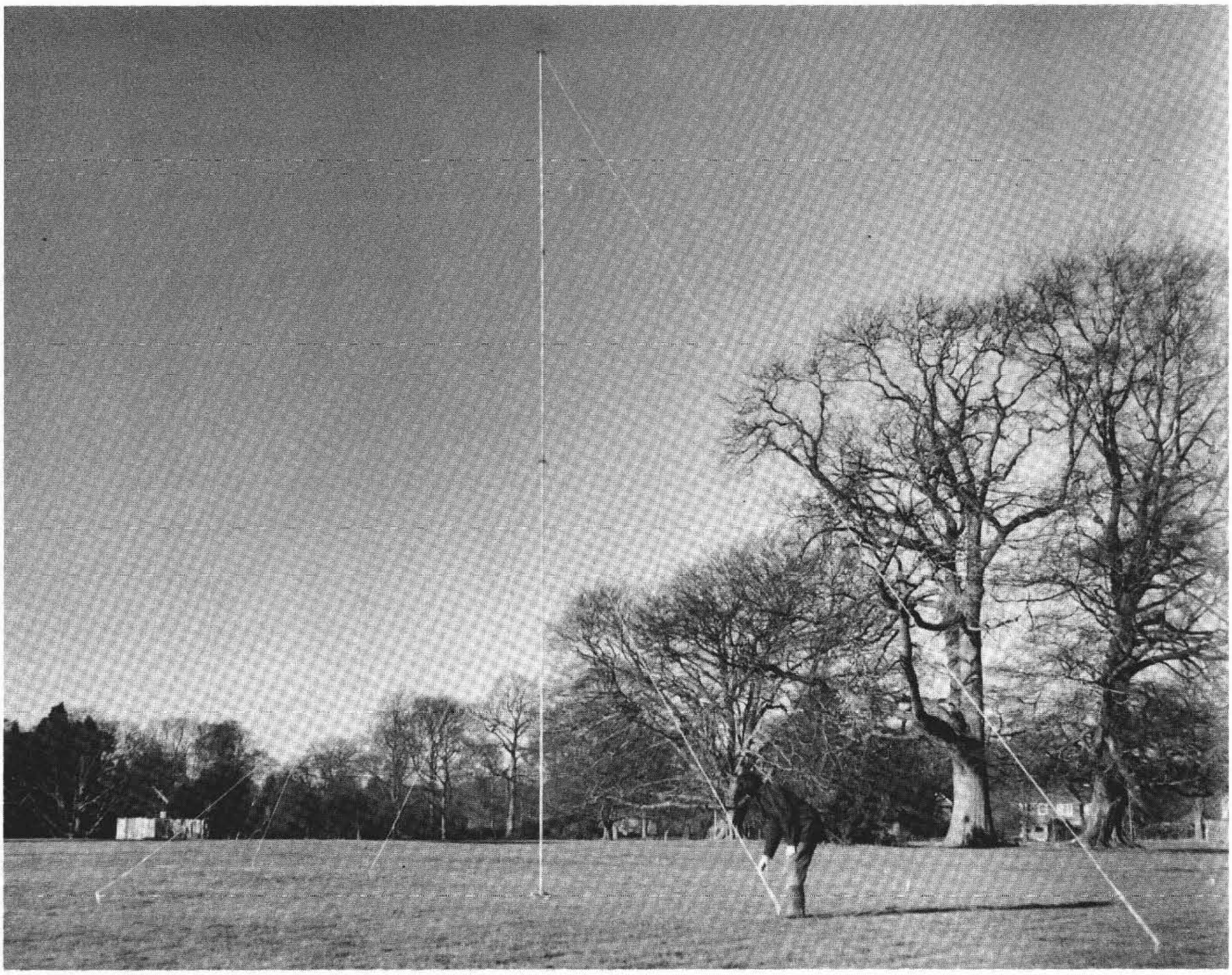

Fig. 2 - The 10 metre mast

The voltmeter is a model manufactured specifically for the measurement of high voltages at radio frequency. However, its response begins to fall at frequencies below about 1 MHz, being 3 dB down at about 100 kHz and thus it required calibration against a meter of known accuracy. The majority of multimeters have their accuracy specified only over a limited range of audio frequencies. The digital voltmeters which were to hand had an input slew-rate limit: the product of frequency, in MHz, and voltage could not exceed 20. A valve voltmeter was found which had a frequency response specified flat to beyond 100 MHz and with adequate input voltage capability, but this meter suffered from a long warm-up period and was too susceptible to being tilted slightly. The procedure finally adopted was to calibrate the valve voltmeter at 1 kHz against a digital voltmeter, and relying on the meter's flat frequency response, to use it as a transfer standard to calibrate the high-voltage r.f. meter.

It is believed that the error in the base voltage thus measured does not exceed 1%.

The terrain in which the calibration is carried out is all-important, and care was taken in choosing a suitable site. If there are any underground conductors, currents are induced in them, because the skin depth in the ground is significant at l.f. and m.f. The consequent re-radiation disturbs the magnetic field measurement. The ground must be level, as mentioned previously. The area in which the measurements are made should be free of buildings, structures, trees, etc., because these cause local reductions in the electric field strength.

Two approaches may be taken to test the suitability of the site. The first is to check that the

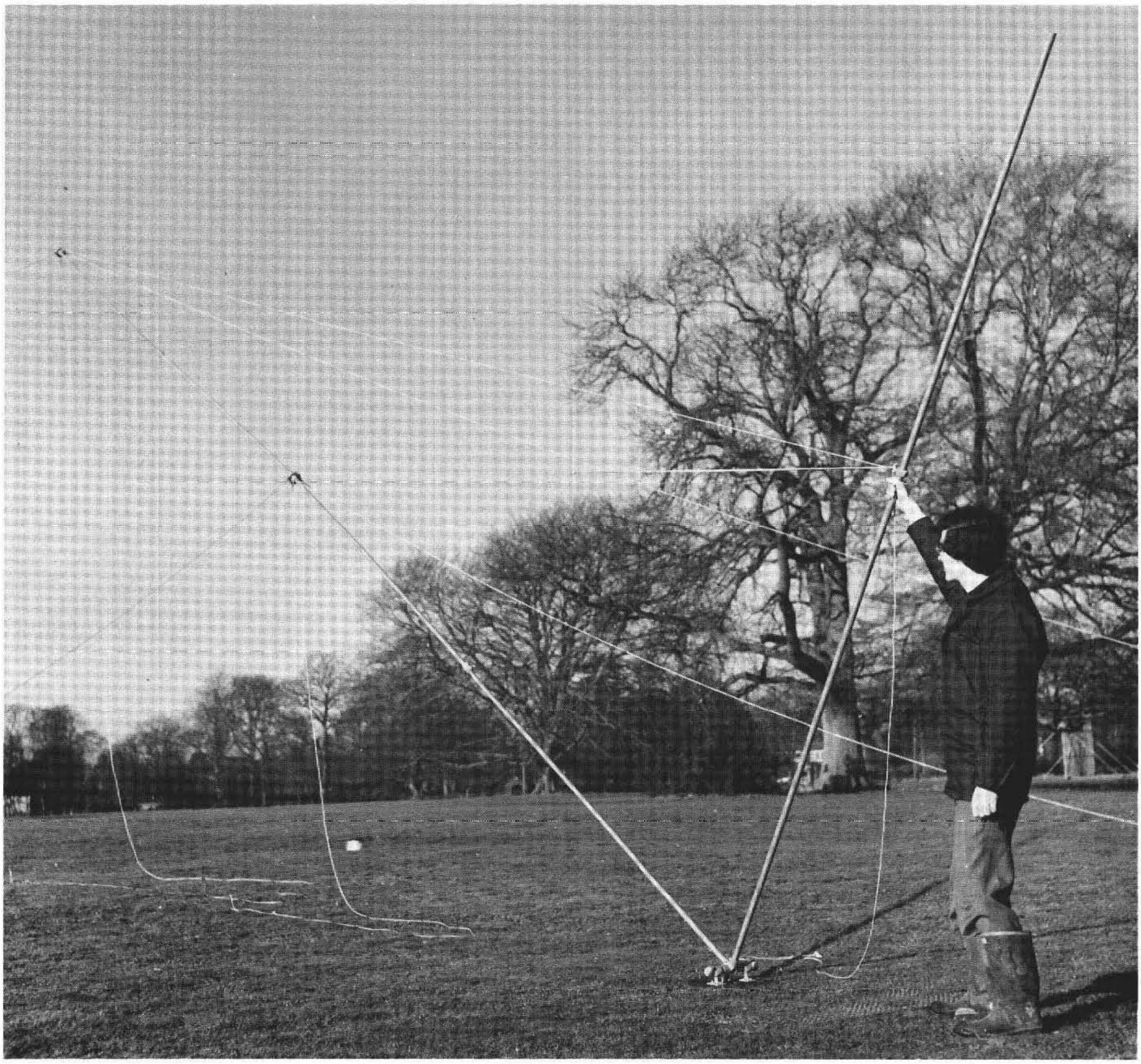

Fig. 3 - Raising the mast

transmission is omnidirectional. The second requires a field strength measuring receiver which will give accurate relative measurements over a wide dynamic range, such as the RC1M/21. This permits a check that the field strength - distance relation agrees with theory. This not only tests the terrain, but also serves to increase general confidence in the calibration method and the agreement between theory and practice.

The *E* to *H* ratio in the vicinity of the monopole is much greater than the free space value. It is therefore essential that the loop antenna of the receiver is well balanced, or carefully shielded from electric fields, in order that reliable magnetic field measurements may be made. The RC1M/21 satisfactorily meets this requirement.

4. Results

The characteristic impedance given by eq. (4) is 342Ω for the longer monopole and 300Ω for the shorter. The values obtained by measurement, applying eq. (3), are respectively 334Ω (over the l.f. band) and 294Ω (over the m.f. band). They show good agreement with eq. (4). The slight

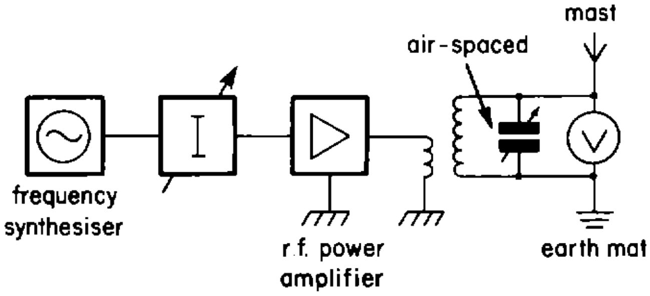

Fig. 4 - Block schematic of calibration transmitter

differences may be due to the fittings on the mast. The error of measurement was estimated as 1-2%.

Table 1 gives some calculated field strengths. The measured values of the characteristic impedance have been used. Both *E* and *H* fields are shown at the extreme frequencies in each band and for distances of 15 m and 100 m from the monopole. A receiving antenna height of 1.75 m above the ground has been assumed; this only has a small effect. The electric field is given in dB relative to 1 μV/m and the magnetic field in dB relative to 1/120π μA/m. (This gives the same number in decibels for *H* as for *E* when the fields are in the free space ratio.) The table shows that useful field strengths are obtained over the ranges indicated.

Some chart recordings of field strength against distance are shown in Fig. 5. Fig. 5(a) was recorded with a whip antenna and Fig. 5 (b) with a loop antenna. Both sets of measurements were made at 1500 kHz. Calculated curves are shown superimposed so that the field strength - distance law can be checked. The calculated curves have been translated vertically to obtain the best fit, and they agree closely with the measurements. This suggests that the calibration method can be expected to give reliable results.

The distance through which the curves are translated yields the calibration constant for the receiver at this frequency, which is the result desired from the experiment. We have found in practice, when calibrating a receiver, that it is more satisfactory to take spot measurements, by noting the readings directly from the receiver. There are several reasons for this. For instance the alignment of measured and computed curves is a matter of judgement and subject to error; also errors can easily arise in the chart recording.

Frequency	*E* 15 m	*E* 100 m	*H* 15 m	*H* 100 m	V_B	h
148 kHz	115.7	68.6	90.9	59.3	300 V	10.29 m
284 kHz	115.6	67.9	96.6	65.9		
519 kHz	102.8	55.5	88.1	58.8	200 V	5.15 m
1607 kHz	101.9	75.5	98.9	76.2		

Table 1 - Calculated field strengths for calibration system

E fields in dB rel. 1 μV/m

H fields in dB rel. 1/120π μA/m

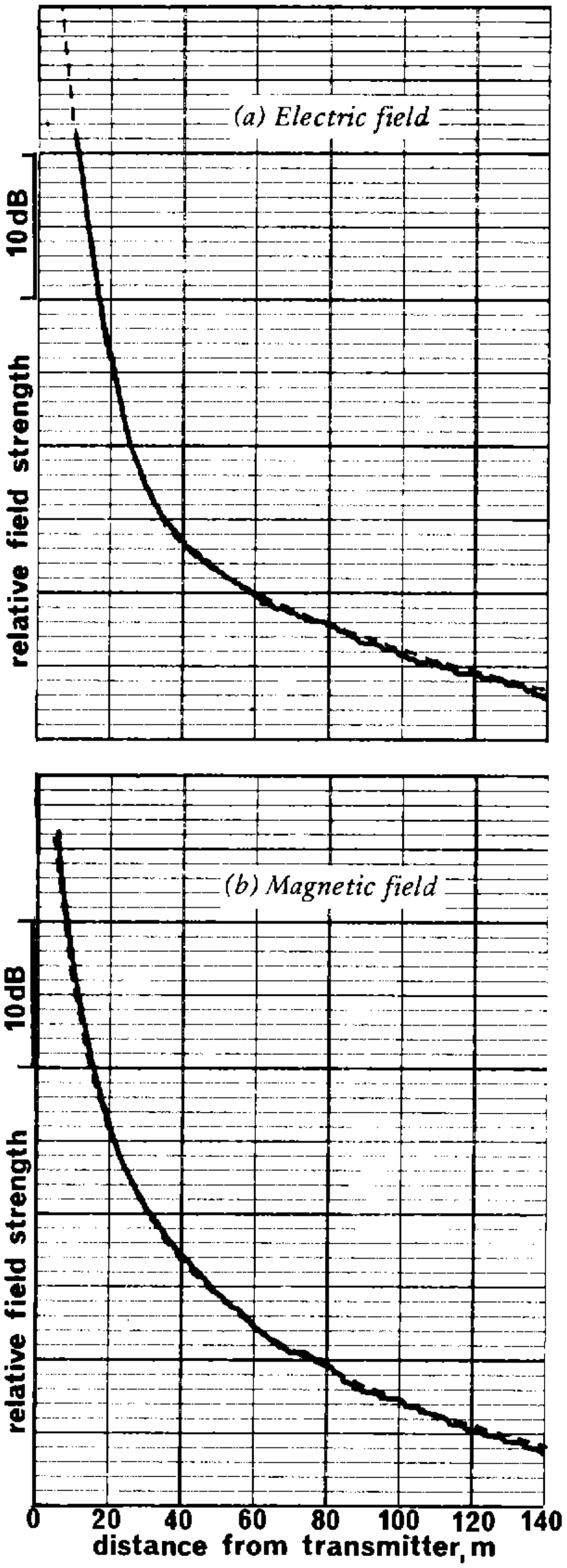

Fig. 5 - Comparison between measured and calculated field strength - distance curves at 1500 kHz

Measured ----- Calculated

5. Conclusions

A method of obtaining known field strengths has been described. Provided that the transmitter is placed on a suitable site, the errors in the E and H field strengths and the E to H ratio, should be within ±1 dB. This applies at least over the range of distances 15 m to 100 m from the transmitter. The precautions and practical considerations are important and have been covered in some detail.

The method is not suitable for the routine checking of receivers. This may be done by substitution or by off-air measurements.

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